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WIRELESS COMMUNICATIONS SYSTEM HAVING VARIABLE GAIN MIXER

TECHNICAL FIELD

The present invention relates, in general, to wireless communications systems and, in particular, to adjusting the power of a wireless communications system so that the dynamic range of the system can accommodate the appropriate wireless standard.

BACKGROUND OF THE INVENTION

Referring to Figure 1, which is a block diagram of a conventional wireless communications transceiver system, an incoming input signal having a radio frequency carrier modulated by an incoming baseband signal component, for example an audio signal component, is received by an antenna **10** and is conducted through a diplexer **11** to a low noise amplifier **12** where it is amplified. The frequency of the amplified radio frequency signal is converted to an intermediate frequency signal by a radio frequency mixer **14** and the intermediate frequency signal is amplified by a variable gain amplifier **16**. The amplified intermediate frequency signal is converted to a low frequency signal by an intermediate frequency mixer **18** and the low frequency signal is amplified by a variable gain amplifier **20**. The amplified low frequency signal is supplied to a demodulator **22** where it is demodulated to detect the incoming audio component and the incoming audio component is amplified by an audio amplifier **24** and supplied to a speaker **26** from which a user hears the incoming audio component carried by the incoming radio frequency signal.

This conventional wireless communications transceiver system also has a microphone **28** that receives an audio input from a user and develops an audio signal that is amplified by an audio amplifier **30** and modulates, in a modulator **32**, a low frequency signal. This modulated low frequency signal is amplified by a variable gain amplifier **34** and the amplified low frequency signal is converted to an intermediate frequency signal by an IF mixer **36**. The

intermediate frequency signal is amplified by a variable gain amplifier **38** and the amplified intermediate frequency signal is converted to a radio frequency signal by an RF mixer **40**. The radio frequency signal is amplified by a driver amplifier **42** and the amplified radio frequency signal is conducted through diplexer **11** to antenna **10** for transmission.

Generally, mixers in communications equipment have a fixed gain. Examples of such mixers are Gilbert cell mixers, FET mixers, and diode mixers.

Referring to Figure 2, which is a circuit diagram of a conventional Gilbert cell mixer included in a conventional wireless communications transceiver system, this mixer circuit includes a mixer core circuit or mixer quad composed of a plurality of transistors **50, 52, 54,** and **56**. The mixer quad provides a switching action at a rate equal to the frequency of a local oscillator signal applied at a local oscillator port **LO P** and **LO N**. This switching action, responsive also to two current signals supplied from the collectors of a pair of transistors **58** and **60** in an input section circuit, converts the frequency of an input signal applied at an input port **IN P** and **IN N** to a different frequency output signal that is produced at an output port **OUT P** and **OUT N**. The input section circuit also includes a pair current sources **62** and **64** connected in series with transistors **58** and **60**, respectively, and a resistor **66** connected between the emitters of transistor **58** and **60**.

In a transmitter application, the signal applied at input port **IN P** and **IN N** is an intermediate frequency signal and the local oscillator switching action produces a radio frequency signal at output port **OUT P** and **OUT N**. In a receiver application, the signal applied at input port **IN P** and **IN N** is a radio frequency signal and the local oscillator switching action produces an intermediate frequency signal at output port **OUT P** and **OUT N**. The input section circuit serves to translate a voltage input signal into two current signals supplied to the mixer quad from the collectors of transistors **58** and **60**.

In the absence of any voltage difference between the base of transistor **58** and the base of transistor **60**, the collector currents of these two

transistors are essentially equal. Thus, a voltage applied to the local oscillator port **LO P** and **LO N** results in no change of output current. Should a small DC offset voltage be present at the input port **IN P** and **IN N** (e.g., due to a mismatch in the emitter areas of transistors **58** and **60**), this will only result in a small feed through of the local oscillator signal to the output port **OUT P** and **OUT N** which will be blocked by a first filter (not shown). Conversely, if an input signal is applied to the input port **IN P** and **IN N**, but no voltage difference is applied to the local oscillator port **LO P** and **LO N**, the output currents will again be balanced. A small offset voltage (due now to emitter mismatch in transistors **50, 52, 54** and **56**) may cause some input signal feed through to the output port **OUT P** and **OUT N**. As before, this will be rejected by the filter. Thus, it is only when a signal supplied to both the local oscillator port **LO P** and **LO N** and the input port **IN P** and **IN N** that a signal appears at the output port **OUT P** and **OUT N**.

If the loads **68, 70, 72,** and **74** are purely resistive and equal, the gain of the circuit is approximately equal to Z/R where Z is the impedance of each of the loads **68, 70, 72,** and **74** and R is the resistance of a resistor **66**. Transistors **58** and **60** modulate the outputs of current sources **62** and **64** at the frequency of the signal at input port **IN P** and **IN N** and provide a high impedance to the emitters of transistors **68, 70, 72,** and **74** of the mixer quad. This high impedance improves the common-mode rejection of the circuit.

Resistor **66** also acts as emitter degeneration that provides increased linearity at the input of the mixer. One measure of mixer linearity is the power gain compression point IP1dB. This parameter can be measured at the input IP1dB or at the output OP1dB. OP1dB is equal to IP1dB plus the gain of the mixer.

As indicated, variable gain amplifiers are provided in both the receiver chain and the transmitter chain. The gain in each chain is adjusted based on the levels o f the received and transmitted signals and what is needed to maintain appropriate signal levels. As arranged in Figure 1, the wireless communications transceiver system is more complex than desired and requires more space than desired.

It has been suggested in the past to arrange the mixers with variable gains to improve the facility to adjust the power of a wireless communications system. While variable gain mixers add to the facility to adjust the power of a wireless communications system, typically there is a loss in linearity and a loss in the rejection of harmonics.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a new and improved wireless communications transceiver system.

It is another object of the present invention to provide a new and improved variable gain mixer for a wireless communications transceiver system.

A wireless communications transceiver system, constructed in accordance with the present invention, includes an antenna for receiving an incoming radio frequency input signal having a radio frequency carrier modulated by an incoming audio signal component and a low noise amplifier for amplifying the radio frequency input signal. Also included in this system is a first radio frequency variable gain mixer having (a) means for supplying a first local oscillator signal, (b) a first input section circuit responsive to the amplified radio frequency input signal for translating the amplified radio frequency input signal from a voltage signal to first and second constant current signals, and (c) a first mixer core circuit responsive to the first and second constant current signals and the first local oscillator signal for developing a differential mixed intermediate frequency input signal. A wireless communications transceiver system, constructed in accordance with the present invention, further includes a first intermediate frequency variable gain mixer having (a) means for supplying a second local oscillator signal, (b) a second input section circuit responsive to the differential mixed intermediate frequency input signal for translating the differential mixed intermediate frequency input signal from a voltage signal to third and fourth constant current signals, and (c) a mixer core circuit responsive to the third and fourth constant current signals and the second local oscillator signal for developing a differential mixed low frequency input signal. A demodulator

detects the incoming audio signal component from the differential mixed low frequency input signal and a first audio amplifier amplifies the incoming audio signal component and supplies the amplified audio signal component to a speaker for converting the amplified incoming audio signal component to incoming audio. A wireless communications transceiver system, constructed in accordance with the present invention, also includes a microphone for converting outgoing audio to an outgoing audio signal component, a second audio amplifier for amplifying the outgoing audio signal component and a modulator for developing an outgoing low frequency output signal having a low frequency carrier modulated by the outgoing audio signal component. Also included in this system is a second intermediate frequency variable gain mixer having (a) means for supplying a third local oscillator signal, (b) a third input section circuit responsive to the low frequency output signal for translating the low frequency output signal from a voltage signal to fifth and sixth constant current signals, and (c) a third mixer core circuit responsive to the fifth and sixth constant current signals and the third local oscillator signal for developing a differential mixed intermediate frequency output signal. A wireless communications transceiver system, constructed in accordance with the present invention, further includes a second radio frequency variable gain mixer having (a) means for supplying a fourth local oscillator signal, (b) a fourth input section circuit responsive to the intermediate frequency output signal for translating the intermediate frequency output signal from a voltage signal to seventh and eighth constant current signals, and (c) a fourth mixer core circuit responsive to the seventh and eighth constant current signals and the fourth local oscillator signal for developing a differential mixed radio frequency output signal. A driver amplifier amplifies the radio frequency output signal and supplies the amplified radio frequency output signal to an antenna for transmitting the amplified radio frequency output signal.

A variable gain mixer, constructed in accordance with the present invention, includes means for supplying a first input signal and means for supplying a second input signal. This mixer also includes an input section circuit responsive to the first input signal for translating the first input signal from a voltage signal to first and second constant current signals. The input section circuit has a plurality of pairs of transducers with each pair of transducers

connected in a differential configuration. The outputs of a first of each pair of transducers are connected together for supplying a first of the first and second constant current signals and the outputs of a second of each pair of transducers are connected together for supplying a second of the first and second constant current signals. The inputs of a first of each pair of transducers are connected together for receiving the first input signal and the inputs of a second of each pair of transducers are connected together and for receiving the first input signal. The input section circuit of the mixer also has a plurality of resistors each connected between a first of each pair of the transducers and a second of each pair of the transducers and a plurality of pairs of constant current sources, a first of each pair connected in series with a first of each pair of the transducers and a second of each pair connected in series with a second of each pair of the transducers. The input section circuit of the mixer further has means for selectively activating a pair of the constant current sources to produce the first constant current signal at the output of the transducer connected in series with the activated first constant current source and the second constant current signal at the output of the transducer connected in series with the activated second constant current source. A variable gain mixer, constructed in accordance with the present invention, further includes a mixer core circuit responsive to the first and second constant current signals and the second input signal for developing a differential mixed output signal that is the product of the constant current signals and the second input signal.

It is to be understood that the foregoing general description of the present invention and the following detailed description of the present invention are exemplary, but are not restrictive of the invention.

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a block diagram of a conventional wireless communications transceiver system.

Figure 2 is a circuit diagram of a conventional mixer that can be included in a conventional wireless communications transceiver system such as the one illustrated in Figure 1.

Figure 3 is a block diagram of a wireless communications transceiver system constructed in accordance with the present invention.

Figure 3A is a block diagram of a portion of wireless communications transceiver system constructed in accordance with the present invention.

Figure 4 is a circuit diagram of a first embodiment of a mixer constructed in accordance with the present invention that can be included in a wireless communications transceiver system such as the one illustrated in Figure 3.

Figure 5 is a circuit diagram of the input section circuit of a second embodiment of a mixer constructed in accordance with the present invention that can be included in a wireless communications transceiver system such as the one illustrated in Figure 3.

Figure 6 is a circuit diagram of the input section circuit of a third embodiment of a mixer constructed in accordance with the present invention that can be included in a wireless communications transceiver system such as the one illustrated in Figure 3.

DETAILED DESCRIPTION OF THE INVENTION

Figure 3 is a block diagram of a wireless communications transceiver system constructed in accordance with the present invention. The Figure 3 wireless communications transceiver system is very similar to the wireless communications transceiver system of Figure 1, with the following differences. The four mixers **80**, **82**, **84**, and **86** are variable gain mixers and the inclusion of the variable gain amplifiers **16**, **20**, **34**, and **38** is optional and

dependent upon the design of the wireless communications transceiver system. The inclusion or omission of the variable gain amplifiers is determined by the needs of the system and the gain introduced by variable gain mixers **80, 82, 84,** and **86**.

Accordingly, the Figure 3 wireless communications transceiver system includes an antenna **10** for receiving an incoming radio frequency input signal having a radio frequency carrier modulated by an incoming audio signal component and a diplexer **11** for conducting the incoming radio frequency input signal to a low noise amplifier **12** where it is amplified. The amplified radio frequency input signal is supplied to a first radio frequency variable gain mixer **80** that develops a differential mixed intermediate frequency input signal.

The differential mixed intermediate frequency input signal is supplied to a first intermediate frequency variable gain mixer **82**, either directly or via a variable gain amplifier **16** depending on the design of the system, that develops a differential mixed low frequency input signal. The low frequency input signal is supplied to a demodulator **22**, either directly or via a variable gain amplifier **20** depending on the design of the system, that detects the incoming audio signal component from the differential mixed low frequency input signal. A first audio amplifier **24** amplifies the incoming audio signal component and a speaker **26** converts the amplified incoming audio signal component to incoming audio.

A wireless communications transceiver system, constructed in accordance with the present invention also includes a microphone **28** for converting outgoing audio to an outgoing audio signal component. The outgoing audio signal component is amplified by a second audio amplifier **30** and the amplified outgoing audio signal component is supplied to a modulator **32** that develops an outgoing low frequency output signal having a low frequency carrier modulated by the outgoing audio signal component. The outgoing low frequency output signal is supplied to a second intermediate frequency variable gain mixer **84**, either directly or via a variable gain amplifier **34** depending on the design of

the system, that develops a differential mixed intermediate frequency output signal.

The intermediate frequency output signal is supplied to a second radio frequency variable gain mixer **86**, either directly or via a variable gain amplifier **38** depending on the design of the system, that develops a differential mixed radio frequency output signal. The radio frequency signal is amplified by a driver amplifier **42** and the amplified radio frequency signal is conducted through diplexer **11** to antenna **10** for transmission.

Each radio frequency variable gain mixer **80** and **86** and each intermediate frequency variable gain mixer **82** and **84** includes means for supplying a local oscillator signal, an input section circuit responsive to an input signal (i.e., a radio frequency signal, an intermediate frequency signal, or a low frequency signal) for translating the input signal from a voltage signal to a pair of constant current signals, and a mixer core circuit responsive to the constant current signals and the local oscillator signal for developing a differential mixed signal (i.e., a radio frequency signal, an intermediate frequency signal, or a low frequency signal). Figures 4, 5 and 6 illustrate three embodiments of the variable gain mixers **80**, **82**, **84**, and **86** constructed in accordance with the present invention.

It should be noted that, while the information received or transmitted by the Figure 3 wireless communications transceiver system has been described as audio, other forms of information, such as video or digital data, can be received or transmitted by a wireless communications transceiver system constructed in accordance with the present invention. This is indicated by Figure 3A in which a block **90**, identified as a baseband processor, represents the reception and transmission of a various forms of information by the Figure 3 wireless communications transceiver system.

Referring to Figure 4, the input section circuit **100** of the variable gain mixer, constructed in accordance with the present invention, includes a plurality of pairs of transducers with each pair of transducers connected in a

differential configuration and the outputs of a first of each pair of the transducers connected together for supplying one of the constant current signals and the outputs of a second of each pair of the transducers connected together for supplying the other of the constant current signals. For the embodiment of the invention illustrated in Figure 4, the pairs of transducers are pairs of identical transistors **102a**, **102b** ..... **116a**, **116b**. The inputs, namely the bases, of a first of each pair of the transistors are connected together for receiving the input signal applied at the input port **IN P** and **IN N** and the inputs, namely the bases, of a second of each pair of the transistors are connected together for receiving the input signal applied at the input port **IN P** and **IN N**.

The input section circuit of the Figure 4 variable gain mixer also includes a plurality of impedances, in the form of resistors **118** ..... **132**, each connected between a first of each pair of the transistors and a second of each pair of the transistors, namely between the emitters of **102a** and **102b** ..... **116a** and **116b**. In particular, resistors **118** ..... **132** are connected between the emitters of transistors pairs **102a**, **102b** ..... **116a**, **116b**. Resistors **118** ..... **132** act as emitter degeneration.

The input section circuit **100** of the Figure 4 variable gain mixer also includes a plurality of pairs of identical constant current sources **134a**, **134b** ..... **148a**, **148b**. Resistors **118** ..... **132** are connected between pairs of constant current sources **134a**, **134b** ..... **148a**, **148b**. A first of each pair of the constant current sources is connected in series with a first of each pair of the transistors **102a**, **102b** ..... **116a**, **116b** and a second of each pair of the constant current sources connected in series with a second of each pair of the transistors **102a**, **102b** ..... **116a**, **116b**. A first of each pair of constant current sources **134a**, **134b** ..... **148a**, **148b** supplies the first constant current signal and a second of each pair of the constant current sources supplies the second constant current signal.

Constant current sources **134a**, **134b** ..... **148a**, **148b** are normally OFF. Accordingly, the input section **100** of the Figure 4 variable gain mixer also includes means for selectively activating a pair of the constant current sources to produce the first constant current signal at the output (i.e., the collector) of the

transistor connected in series with the activated first constant current source and the second constant current signal at the output (i.e., the collector) of the transistor connected in series with the activated second constant current source. Such means are presented by a plurality of terminals **150** ...... **164** to which control signals are applied selectively to activate that pair of constant current sources **134a, 134b** ..... **148a, 148b** associated with that pair of transistors **102a, 102b** ..... **116a, 116b** and resistor **118** ..... **132** associated with the activated constant current sources that will produce the desired gain for the mixer.

As indicated in Figure 4, transistor pairs **102a, 102b** ..... **116a, 116b** are connected to a DC bias voltage source that biases the transistor pairs with a DC bias voltage V_{b1}. In contrast to prior art variable gain mixers, in which the gain is varied by varying the bias voltage, the bias voltage of a variable gain mixer constructed in accordance with the present invention is fixed, so that the currents at the outputs of transistors **102a, 102b** ..... **116a, 116b** that are connected in series with the pair of activated constant current sources **134a, 134b** ..... **148a, 148b** are constant. The gain of this mixer is varied by the value of the emitter degeneration resistor **118** ..... **132** that is connected between the pair of constant current sources **134a, 134b** ..... **148a, 148b** that is activated.

The mixer core circuit **170** of the Figure 4 mixer includes four transistors **50, 52, 54** and **56** connected as a doubly-balanced switching modulator. The mixer core circuit **170**, responsive to the constant current signals and the local oscillator signal applied at local oscillator port **LO P** and **LO N**. develops a differential mixed output signal at an output port **OUT P** and **OUT N** that is the product of the current signals and the local oscillator signal. Because of the fixed DC bias voltage V_{b2} applied to transistors **50, 52, 54** and **56** from a DC bias voltage source, the output currents at output port **OUT P** and **OUT N** are constant. The gain of the mixer is determined by the ratio of the impedance of each of the loads **68, 70, 72,** and **74** and the resistance of that emitter degeneration resistor **118** ..... **132** that is connected between the pair of constant current sources **134a, 134b** ..... **148a, 148b** that is activated.

By maintaining a constant DC current, the linearity of a variable gain mixer, constructed in accordance with the present invention, is maintained constant. In addition, because harmonic distortion changes with changes in the DC current, there are no changes in harmonic rejection with a variable gain mixer constructed in accordance with the present invention.

Referring to Figure 5, which is a circuit diagram of the input section circuit of a second embodiment of a mixer constructed in accordance with the present invention, this input section circuit includes a single pair transducers, in the form of transistors **172** and **174**, connected in a differential configuration, a single pair of constant current sources **176** and **178**, and a plurality of series-connected resistor/FET branches **180a** ..... **180n**. In this embodiment of a mixer constructed in accordance with the present invention, the gain of the mixer is established by selectively activating one of the FET's by application of a control signal at one of a plurality of terminals **182a** ..... **182n** and connecting into the circuit the emitter degeneration resistor connected in series with the activated FET. With a fixed bias voltage V_{b1} applied to transistors **172** and **174** from a DC bias voltage source, the currents at the outputs of these transistors are constant. The input section circuit of Figure 5 can be used with the mixer core circuit **170** illustrated in Figure 4.

Referring to Figure 6, which is a circuit diagram of the input section circuit of a third embodiment of a mixer constructed in accordance with the present invention, this input section circuit includes a single pair transducers, in the form of transistors **172** and **174**, connected in a differential configuration, a single pair of constant current sources **176** and **178**, and a plurality of series-connected inductor/FET branches **184a** ..... **184n**. In this embodiment of a mixer, constructed in accordance with the present invention, the gain of the mixer is established by selectively activating one of the FET's by application of a control signal at one of a plurality of terminals **182a** ..... **182n** and connecting into the circuit the emitter degeneration inductor connected in series with the activated FET.. With a fixed bias voltage V_{b1} applied to transistors **172** and **174** from a DC bias voltage source, the currents at the outputs of these transistors are constant.

The input section circuit of Figure 6 can be used with the mixer core circuit **170** illustrated in Figure 4.

Although illustrated and described above with reference to certain specific embodiments, the present invention nevertheless is not intended to be limited to the details shown. Rather various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the spirit of the invention.